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ASH CONDITIONING FOR IMPROVED ESP PERFORMANCE

Report No 88-138-K

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ABSTRACT

Ash conditioning to reduce high ash resistivities and improve ESP collection efficiencies when burning a low sulphur western Canadian (Luscar) coal and a western Canadian-U.S. coal blend with limestone injection has been conducted at Ontario Hydro's 640 MJ/h combustion research facility. The Luscar coal produced a stable flame and carbon burnout was 99.9%. Ash resistivities measured in situ ranged between 2.7×10^{10} to 1.4×10^{11} ohm.cm. The pilot precipitator performed only with 79% efficiency. SO_3 conditioning of the Luscar coal ash with 50 ppm SO_3 injected into the flue gas decreased the resistivity by 0.7 to 1 order of magnitude and improved the collection efficiency of the ESP by 6%. Conditioning the waste of the western Canadian-U.S. coal blend during limestone injection was carried out using both SO_3 and water. Injection of about 60 ppm SO_3 vapour into the flue gas to condition the limestone injection waste reduced the resistivity from 10^{11} ohm.cm by up to 3 orders of magnitude and improved the performance of the electrostatic precipitator by 6% from 87 to 93%. Humidification of the waste at a 58% relative humidity lowered the resistivity from 2.8×10^{11} to 1.8×10^{8} ohm.cm and increased the collection efficiency of the precipitator by approximately 7%.

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EXECUTIVE SUMMARY

ASH CONDITIONING FOR IMPROVED ESP PERFORMANCE

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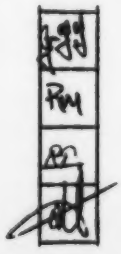
Combustion Chemistry Unit, Process Chemistry Section
Chemical Research Department

Conditioning of high resistivity ashes to improve performance of the electrostatic precipitator has been conducted at Ontario Hydro's 640 MJ/h combustion research facility. The studies were carried out while burning a 0.3% sulphur western Canadian coal from the Luscar Mine of Alberta and a 1.4% sulphur US - western Canadian coal blend with limestone injection.

The Luscar coal burned well with a stable flame, but ash resistivities measured in situ at 140°C were high, ranging between 2.7×10^{10} to 1.4×10^{11} ohm.cm resulting in a poor performance of the pilot scale ESP of 79%. Conditioning of the ash with the injection of 50 ppm SO_3 reduced ash resistivity by 0.7 to 1 order of magnitude and improved ESP collection efficiency by about 6%.

Sorbent injection while burning a western Canadian - US coal blend resulted in 47% SO_2 capture and total SO_2 emission was reduced from 0.96 to 0.51 gSO_2/MJ. The process produced a high resistivity waste of 2.8×10^{11} ohm.cm. Both SO_3 injection and humidification were investigated for conditioning this waste. Humidification appears to be more efficient in reducing resistivities and improving ESP performance than SO_3 conditioning: humidification reduces ash resistivity by up to 3 orders of magnitude from 10^{11} to 10^{8} ohm.cm and increases collection efficiency from 89% to 96%. SO_3 conditioning reduces ash resistivity from 10^{11} ohm.cm by up to 3 orders of magnitude, resulting in 6% ESP efficiency improvement.



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To Mr. I.J. Stuart-Sheppard
Manager - Power Equipment
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ASH CONDITIONING FOR IMPROVED ESP PERFORMANCE

1.0 INTRODUCTION

Ontario Hydro's coal fired stations are equipped with electrostatic precipitators (ESP) for collecting ashes from flue gases. These precipitators were designed for collecting ashes from bituminous coals with a sulphur content ranging between 1.5 - 2.2%. Collection efficiencies drop significantly when these ESP's are used for collecting ashes with resistivities exceeding 5×10^{10} ohm cm. High resistivity ashes are being produced at Nanticoke TGS, where low sulphur coal blends are being burned. High resistivity wastes (a mixture of coal ash and partially sulphated calcine) are also produced from sorbent injection and spray drier technologies used for reducing SO_2 emissions form power plants, currently under development at Ontario Hydro.

High resistivity ash collection by existing precipitators can be improved by changing various parameters in the precipitator design, such as: collection area, residence time, power density, and the use of hot side ESP's. With old ESP's, however, it is either impossible or too expensive to change most of these parameters. Conditioning of high resistivity ashes is an inexpensive option to reduce ash resistivity and improve ESP performance. This report summarizes the results of the ash conditioning studies conducted at the Research Division's Combustion Research Facility in support of the full scale tests carried out in September 1987 at Lakeview TGS.

The objective of the study was to evaluate a number of conditioning agents such as SO_3 and water on the pilot scale, that may be used by Ontario Hydro for conditioning low sulphur coal ashes and sorbent injection wastes in order to improve performance of electrostatic precipitators.

2.0 ASH CONDITIONING

Fly ash collection in the ESP involves ash deposition on the collector plates followed by its removal and collection in the hopper. The various factors affecting ESP efficiency given below are related to the electrical environment in the precipitator and ash properties:

- electric field strength and ion density in the ESP;
- electrical resistivity of the ash;
- adhesion and cohesion characteristics of the ash;
- particle size distribution of the ash;

The conduction of electric current through an ash layer is essential for good precipitator performance, and is related to ash resistivity. The two most important conduction mechanisms are termed volume conduction and surface conduction. Volume conduction is determined by the bulk composition of the ash, and surface conduction depends on an absorbed film on the dust surface, which is related to the composition of the gas and of the dust particle surface./1/

A conditioning agent added to the flue gas usually in trace amounts, may affect some or all the factors influencing ESP performance. Many conditioning chemicals such as SO_3, sulphuric acid, sodium sulphate, sodium carbonate and water provide conductive surface films and enhance surface conductivity (thus reduce ash resistivity). Some chemicals modify the crystal lattice of ash particles and improve volume conductivity./2,3/

Resistivity modifications can also be accomplished by the use of an agent that increases the cohesiveness of the deposited fly ash through interparticle binding forces. Agglomeration of small fly ash particles in the flue gas stream is a potential mechanism for enhancing ESP performance: small particles with diameters between 0.2 to 0.5 microns are generally collected less efficiently by ESP than larger particles. Ammonia is a typical example of this category of chemicals.

The temperature of the flue gas also affects ash resistivity: increasing temperature increases ionic mobility in the ash particle and improves volume conductivity.

The conditioning agents selected for testing include SO_3 and water. Both are reported to be efficient and are widely used for high resistivity ashes.

3.0 EXPERIMENTAL

3.1 COMBUSTION RESEARCH FACILITY

The study was conducted at Ontario Hydro's Combustion Research Facility (CRF) (Figure 1), designed for a maximum coal feed rate of about 20 kg/h US bituminous coal at a firing rate of 640 MJ/h./4/ The furnace is a refractory-lined cylindrical chamber, fully equipped for monitoring gas and wall temperatures. There are multiple ports for flame observation and for insertion of solid sampling probes. There are also probes to determine slagging and fouling rates. The pulverized coal is delivered down-draft to the burner with the combustion air, which can be electrically preheated to temperatures up to 350°C. Gas burners on each side of the coal burner are used to heat the furnace to operating temperatures before beginning to feed the coal.

The coal burner, designed and constructed by Research Division staff, is equipped with a vortex generator and four air vanes to assure good mixing and adequate residence time of the fuel-air mixture in the combustion zone. The combustion gases in the furnace are cooled by water and/or air circulating in a cylindrical Inconel jacket around the furnace. This cooling system is equipped with temperature sensors and flow meters to control furnace quenching rates.

The combustion gases leaving the furnace are further cooled by a series of air-cooled heat exchangers to between 90-400°C prior to entering the resistivity probe housing and ESP. The ESP consists of a cubic stainless steel chamber, and is equipped with two sets of interchangeable cells. The ESP operates at a temperature of approximately 150°C. Particulate mass loading in the flue gas before and after the ESP is measured with an isokinetic sampling system. In-situ resistivity is measured with a point-plane resistivity probe situated in the resistivity probe housing.

The CRF instrumentation permits system temperatures, and flue gas compositions (O_2, CO_2, CO, SO_2 and NO_x) to be monitored continuously. Temperatures are measured with thermocouples and suction pyrometer, and flame temperatures with an optical pyrometer. Flow rates and pressures are measured by flow meters and manometers. All measuring and monitoring systems are linked to a computerized data acquisition system.

3.2 SO_3 CONDITIONING SYSTEM

An SO_3 conditioning system was designed and constructed for studying the effect of SO_3 on the resistivity and precipitability of high resistivity ashes, such as low sulphur western Canadian coal ash and sorbent injection waste. The schematic diagram of the system is shown in Figure 2. The material of construction is stainless steel.

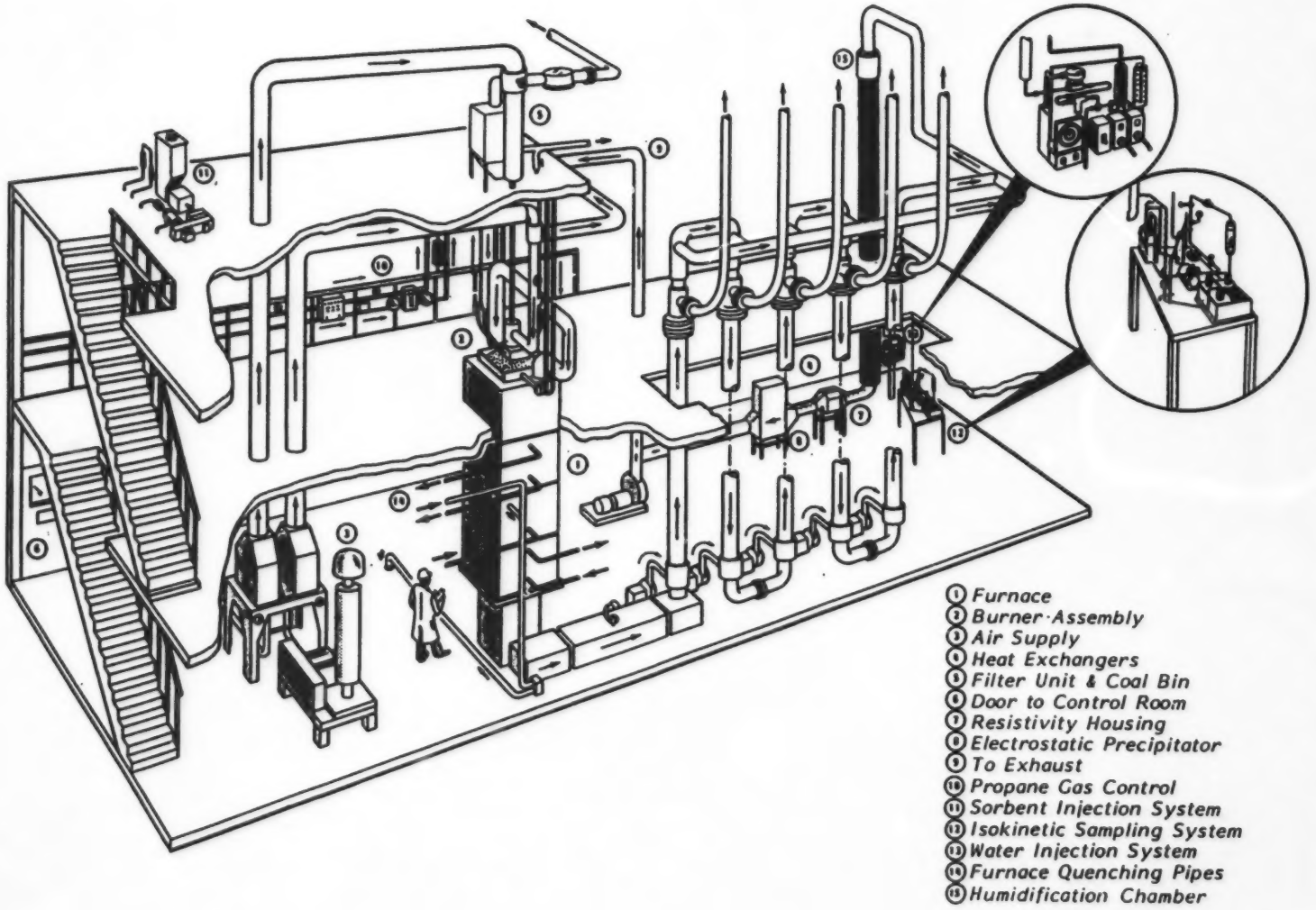

FIGURE 1
COMBUSTION RESEARCH FACILITY

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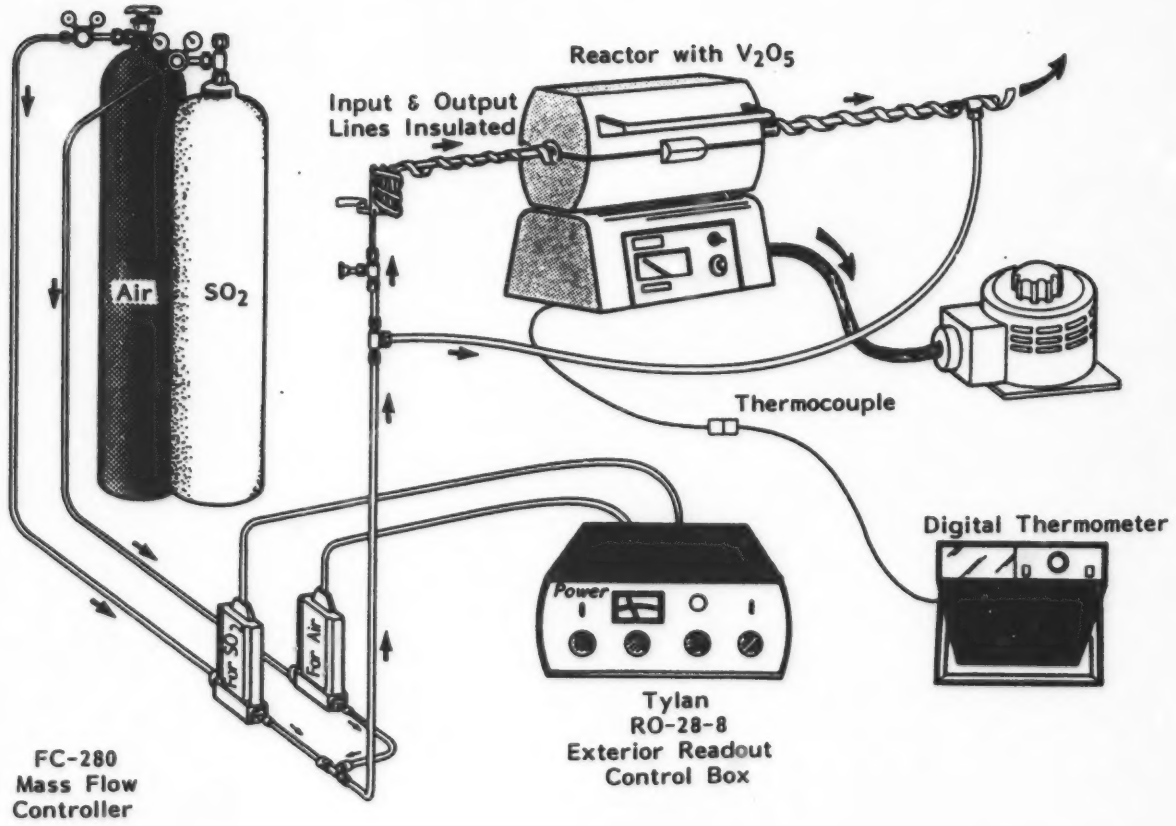

FIGURE 2

SO_3 CONDITIONING SYSTEM

SO_3 is generated by passing SO_2 and air slowly over a vanadium pentoxide catalyst (V_2O_5) bed, at approximately 425°C. The oxidation proceeds according to the following equation and its efficiency is approximately 99.5%.

$$SO_2 + 1/2\ O_2 = SO_3$$

3.3 HUMIDIFICATION CHAMBER

A humidification chamber, 19 cm ID and 5.8 m long, shown in Figure 3 is equipped with three water injection ports, and provides 1 to 3 s gas residence time. The chamber is also equipped with five ports, 61 cm apart, for inserting thermocouples to measure dry-bulb-wet-bulb temperatures and gas drying times. The water injection system consists of a solenoid, electrically controlled by a cyclic timer. The water flow rate is measured by a rotameter upstream of the spray nozzle.

To assure the most favourable environment for moisture conditioning, the operating conditions in the humidifier have been optimized. The most important parameters affecting gas humidity include: a) nozzle type, which determines droplet size, drying time, spray angle and wall wetting, b) temperature and c) particulate's residence time in the humidifier. The humidification experiments were carried out with a Turbobak Caldyn 2mm, which was evaluated in a previous study/5/. The droplet size distribution for this nozzle is shown in Figure 4. Optimum operating conditions in the humidifier are given below:

Inlet gas temperature:	145-155°C
Outlet gas temperature:	65°C
Approach to adiabatic saturation:	8-11°C
Air pressure:	75 - 80 psig
MMD of water droplets:	5-10 µm

The variation of the humidity level in the chamber as a function of residence time was measured and is shown in Figure 5. The residence time in the chamber is a function of the location of the water injection nozzle. As the data indicate, the humidity in the chamber drops sharply in the first two seconds from 57% to 32%. Beyond this, humidity drops very slowly, indicating that the residence time in a humid environment in the chamber is very short.

3.4 SORBENT INJECTION SYSTEM

This system consists of sorbent injection ports installed at five locations along the length of the furnace and a sorbent storage and feeding system. A detailed description of the system is given in reference/4/.

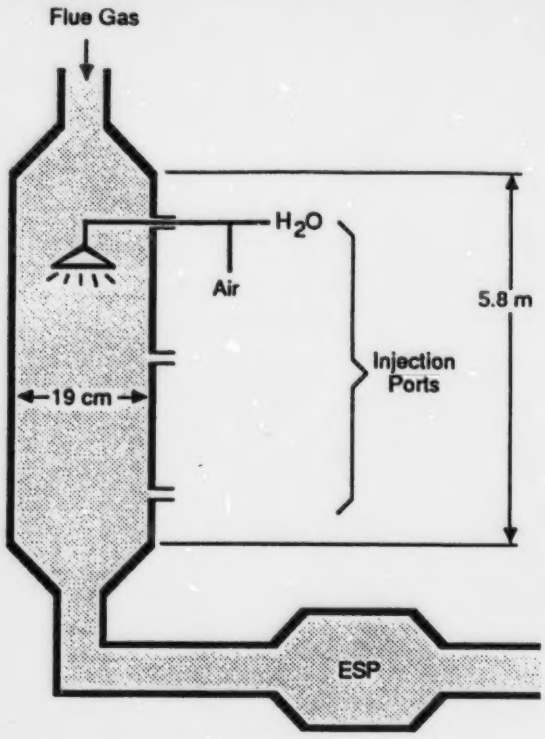

FIGURE 3
HUMIDIFICATION CHAMBER

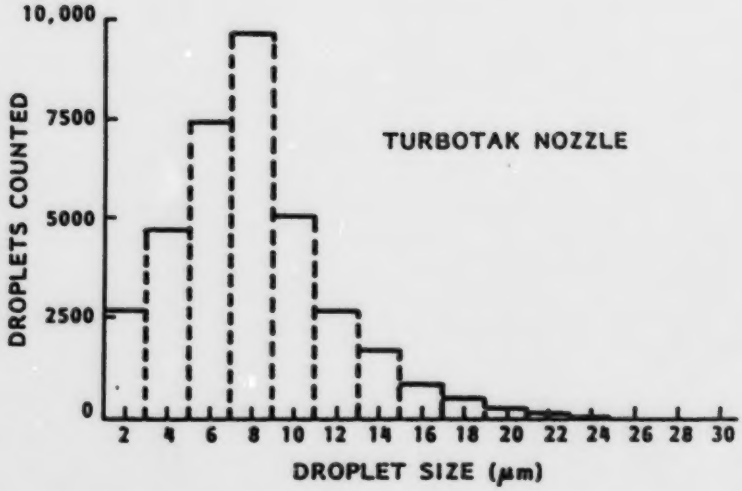

FIGURE 4
DROPLET SIZE DISTRIBUTION

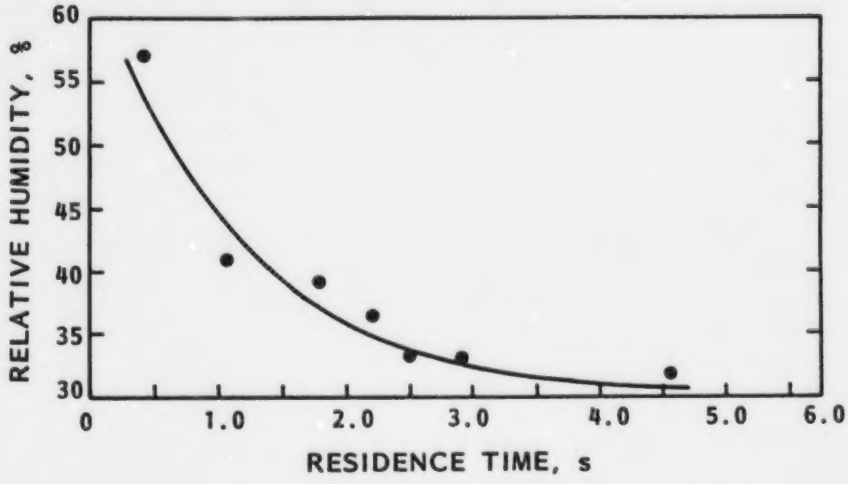

FIGURE 5
RELATIVE HUMIDITY VS RESIDENCE TIME

3.5 SAMPLING AND ANALYSIS

3.5.1 Isokinetic Sampling of Fly Ash and Carbon in Ash

Isokinetic sampling of fly ash was done before the precipitator in order to determine the carbon level of fly ash. A pitot tube located near the 1.27 cm gooseneck nozzle measured the gas velocity in the duct. Once the velocity was established, the gas flow rate through the nozzle was monitored at ambient temperature and corrected for in-stack temperature conditions. Fly ash samples were collected on a glass fibre filter and during sampling the sampling line was heated to stack temperature to avoid water condensation. Loss on ignition (carbon in ash) is done in accordance with Section 36 of methods C114 and C311 of the ASTM procedures.

3.5.2 Continuous Gas Analysis

Flue gas for monitoring O_2, CO_2, CO, SO_2 and NO_x was continuously withdrawn through an in-stack stainless steel probe, at a point where the temperature was approximately 650°C. The gas then passed through a refrigeration unit which removed water by condensation at a temperature of approximately -10°C. The length of the sampling line was made as short as possible and was heated to 120°C to avoid any condensation. The sampling line was cleaned after every test.

3.5.3 Coal Analysis

Coal samples were analyzed to determine ultimate and proximate analysis, heating value and particle size distribution. For the ultimate analysis, carbon and hydrogen gas was determined by the method described in Reference 6. Sulphur was done by the Leco Induction method and nitrogen by the Kjeldahl method as outlined in ASTM D3179. Oxygen was calculated by difference as the last remaining constituent.

Proximate analysis was performed according to ASTM method D3173-D3175 and the calorific value by ASTM method D3286, using an adiabatic bomb calorimeter. Particle size distribution was determined by sieve analysis according to ASTM method D-197.

3.5.4 Ash Analysis

Ash samples collected isokinetically before and after the electrostatic precipitator were analyzed for major mineral oxide concentrations (Al, Si, Na, Mg, Ca, K, Fe, and S), as outlined in Reference 7. Particle size distributions were determined by use of a Sedigraph 5000 D particle size analyzer based on Stoke's Law of Sedimentation at the Ontario Research Foundation.

3.6 PROCEDURES

3.6.1 Firing Conditions

The combustor was heated with propane gas overnight at a rate of 240 MJ/h, achieving temperatures of 900-1000°C on the morning of the planned test. Upon attaining the desired quenching rate of 500°C/s, simulating Lakeview TGS quenching rate, the switch from propane to the coal to be tested was made. The proximate, ultimate and sieve analyses of the two coals used in the study, a sub-bituminous low sulphur coal from Luscar Mines in Alberta and a 50-50 blend of an eastern U.S. - western Canadian coal, and an eastern U.S. bituminous coal for comparison are given in Table 1.

Typical steady state firing conditions for the two coals studied are compared in the table on page 11 with that of an eastern US bituminous coal.

Temperature - time profile and radial temperature profile of flue gases are shown in Figure 6.

3.6.2 SO_3 Conditioning

SO_3 was injected upstream of the ESP through an open ended stainless steel tube after achieving steady state firing conditions. The concentration of SO_3 injected varied between 10 to 70 ppm and the residence time was varied

Table 1 Coal Characteristics

PROXIMATE ANALYSIS, g/kg (AS FIRED)

	US COAL	W. CAN - US COAL BLEND	LUSCAR COAL
Moisture	14	32	71
Ash	80	99	117
Volatile Matter	357	321	328
Fixed Carbon	548	548	483
Heating Value MJ/kg	32	29	26

ULTIMATE ANALYSIS, g/kg (DRY)

	US COAL	W. CAN - US COAL BLEND	LUSCAR COAL
Carbon	756	751	692
Hydrogen	57	47	49
Nitrogen	16	11	11
Sulphur	17	15	3
Ash	80	71	131
Oxygen	74	101	115

PARTICLE SIZE DISTRIBUTION

SIEVE OPENING μ m	US COAL	W. CAN - US COAL BLEND	LUSCAR COAL
150	100	100	100
106	93	98	91
75	73	84	68
63	59	76	57
53	56	63	42
44	51	19	29
< 44			

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Firing Conditions	Luscar Coal	US-bituminous W. Canadian Coal Blend	Eastern US-bituminous Coal
Nominal firing rate, MJ/h	425	420	432
Primary air flow, m^3/min : at 100°C	1.1	1.1	1.1
secondary air flow, m^3/min : at 250°C	3.4	3.4	3.4
Furnace wall temp. profile			
top section,°C:	1350	1350	1380
2nd section,°C:	1100	1100	1100
3d section, °C:	875	875	875
4th section,°C:	860	860	860

between 0.5 to 1.5s by varying the injection location. After SO_3 injection was initiated, a period of about one hour was allowed before resistivity measurements and ESP performance tests were commenced.

4.0 RESULTS AND DISCUSSION

4.1 COMBUSTION PERFORMANCE OF WESTERN CANADIAN LUSCAR COAL AND EASTERN U.S. - WESTERN CANADIAN COAL BLEND

4.1.1 Carbon Burnout and Flame Stability

Combustibility of both the Luscar coal and the western Canadian-U.S. coal blend was satisfactory. Carbon burnout for the Luscar coal was 99.9% and 99.4% for the blend at feed fineness of 68% and 84% by weight passing a 200 mesh screen respectively. Flame stability in both cases was also satisfactory. The results are summarized in table 2 with data for U.S. coal shown for comparison.

4.1.2 Pollutant Emission and Ash Precipitability

Flue gas composition and pollutant emissions normalized to 5% excess oxygen, ash resistivities and particulate collection efficiencies for the two coals studied are compared with that of a US coal in table 2. Flue gas SO_2 content

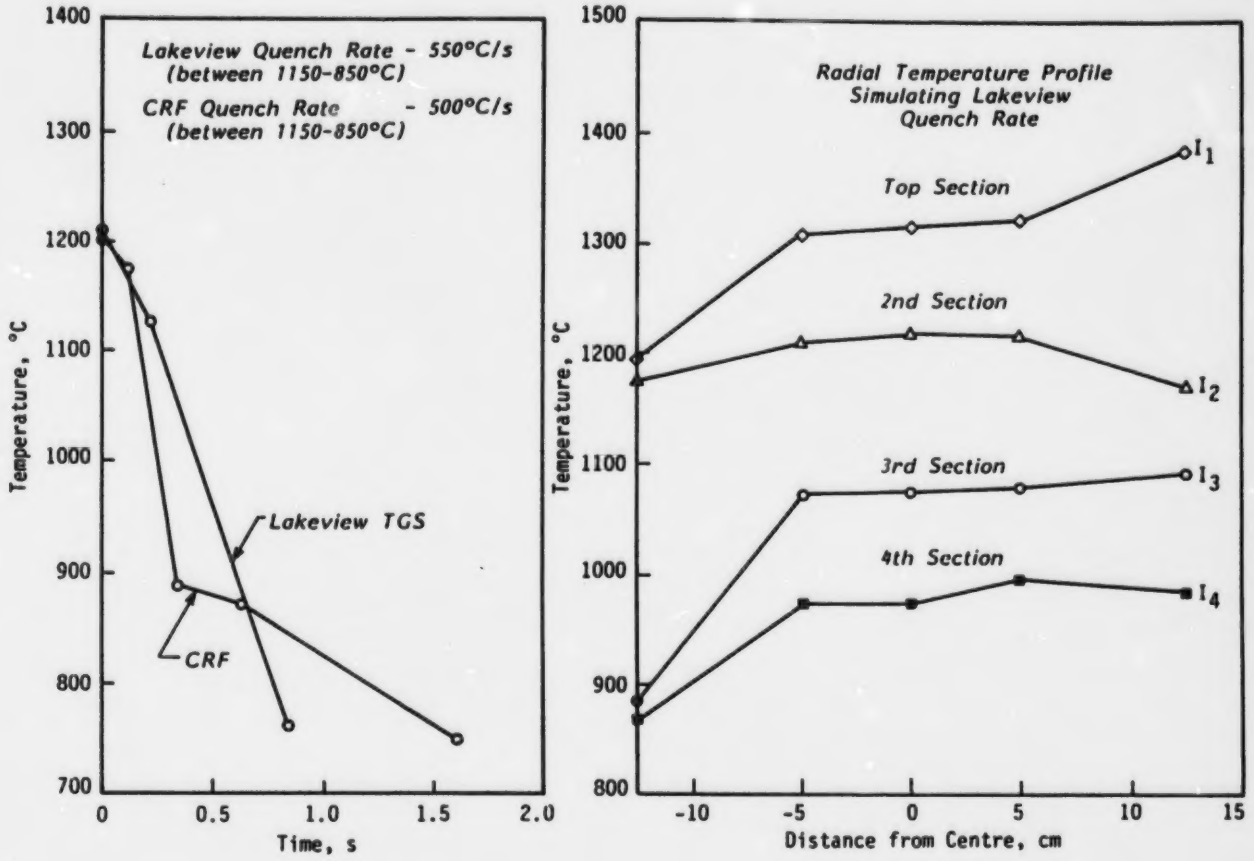

FIGURE 6
TEMPERATURE TIME AND RADIAL PROFILES OF FLUE GASSES

Table 2

Combustion Performance of
Luscar Coal and U.S.-western Canadian Coal Blend

Furnace Quenching Rate = 500 °C/s

	U.S. bituminous Coal	Luscar Coal	U.S. bituminous-western Canadian Coal Blend
Heating value, MJ/kg	32	26	29
Firing Rate, MJ/hr	432	429	420
Flame stability	Stable	Stable	Stable
Carbon in ash, g/kg	31	8	43
Carbon burnout, %	99.5	99.9	99.4
Flue-gas composition (normalized to 5% O_2)			
% CO_2	13.9	15.6	13.4
% O_2	5.0	5.0	5.0
ppm CO	117	31	-
ppm SO_2	1,500	225	940
Emission			
Sulphur gSO_2/MJ	1.1	0.24	0.96
NO_x gNO_x/MJ	0.21		0.28
Ash Resistivity, ohm.cm	8.3×10^7	1.4×10^{11}	5.9×10^6
Dust loading in	3.3	.78	1.2
Dust Loading out	.3	.16	.09
ESP Performance, %	92	80	93
Slagging and Fouling Tendency	None	None	None

(C101)

from the Luscar coal is 225 ppm - 85% lower than from the eastern U.S. bituminous coal. The 1.7%S US coal emits 1.1 g SO_2/MJ compared to 0.96 g SO_2/MJ for the 1.4% S western-Canadian - US coal blend representing a 56% reduction in SO_2 emissions per MJ from the US coal. The low sulphur Luscar coal (0.3%S) only emits 0.24 g SO_2/MJ. NO_x emissions for the blended fuel is slightly higher than for the US coal being 0.28 g/MJ for the blend as compared to 0.21 g/MJ for the US coal. No measurement was made for the Luscar coal.

In-situ ash resistivities were measured at a temperature of approximately 140°C. The U.S. coal ash resistivity is 8.3×10^7 ohm.cm and that of the blend is 5.9×10^6 ohm.cm and precipitator performance is not expected to be a problem. ESP collection efficiencies are 92 and 93% respectively. The resistivity of the low sulphur Luscar coal is 1.4×10^{11} ohm.cm with a collection efficiency of 79%. Although the pilot ESP does not provide absolute values its performance deterioration suggests that some form of conditioning would be required to the Luscar coal ash to reduce high ash resistivities and to improve impaired ESP performance.

4.1.3 Slagging and Fouling Tendency

Combining two or more coals (blend) from different geological locations can cause mineral matter from one coal to combine with mineral matter with another coal to form low melting eutectics giving rise to fireside slagging and fouling on the boiler tubes. Visual observation of the furnace during the coal blend tests indicated only soft deposits on the furnace walls which could be easily blown away by compressed air. The same observation was made during the combustion of the western Canadian Luscar coal.

4.2 LIMESTONE INJECTION USING WESTERN CANADIAN-US COAL BLEND

4.2.1 Sulphur Capture and Sorbent Utilization

In-furnace limestone injection for reducing SO_2 from flue gases of an eastern US-western Canadian coal blend from Nanticoke TGS has been studied at the CRF, under conditions simulating Lakeview TGS quenching rate. The analysis of the coal blend, and of the reference coal, an eastern US bituminous coal is given in Table 1. Chemical and physical characteristics of a Beachville limestone, used in the study is shown in Table 3.

Operating parameters of the process affecting SO_2 capture and sorbent utilization, such as injection temperature and Ca/S ratios were optimized and the waste was characterized. The results of these tests are summarized in Table 4 and plotted in Figure 7. Sulphur capture by the same limestone from a US coal under similar operating conditions is also shown for comparison.

Optimum conditions for sulphur capture by limestone injection from a 1.7% sulphur US coal or from a 1.4% S western Canadian - US coal blend are very similar: highest capture occurs when the limestone is injected at approximately 1100°C into the furnace at a Ca/S ratio of 3.0. Under these conditions 47% of SO_2 was captured by the limestone injected into the furnace when

Table 3

Chemical and Physical Properties of Beachville Limestone

	Beachville Limestone
Li_2O,g/kg	<0.03
Na_2O	0.03
K_2O	0.6
MgO	8.0
CaO	524.0
Fe_2O_3	0.1
Al_2O_3	22.0
SiO_2	<12.0
$Ca(OH)_2$	
LOI	434.0
BET area, m^2/g	1.3
MMD, μm	8.6
ρ, g/cm^3	2.6
Porosity, %	17.0

Table 4
Sorbent Injection - Optimizing Process Variables
(Nanticoke Coal Blend)

US-western Canadian Coal Blend: S = 1.4%
Furnace Quench Rate: 500°C/s
Beachville Limestone: MMD = 8.6μm
Firing Rate: 420 MJ/h

Run No.	SORBENT INJECTION												WASTE					ESP PERFORMANCE			
		INJECTION CONDITIONS			FLUE GAS COMPOSITION*								Composition				kg waste				
	Ca/S Ratio	Location	Temp. °C	Res.Time s	CO_2 %	O_2 %	CO ppm	NO x ppm	SO_2 ppm Before	SO_2 ppm After	SO_2 Capture %	Sorbent Utiliz. %	CaO g/kg	$CaSO_4$ g/kg	$CaCO_3$ g/kg	Carbon g/kg	100 kg coal	Ash Resistivity ohm.cm	Dust Loading g/m^3 Before	Dust Loading g/m^3 After	ESP Eff. %
2 Base-line					13.4	5.0		580	1491				51	23		43	12	$5.9x10^6$	1.2	0.09	93
3A	3.0	I_0	1380	0.7	12.8	5.0			1431	1021	28.8	9.6									
B	3.0	I_1	1362	0.7	12.6	5.0			1438	1004	30.2	10.1									
C	3.0	I_2	1100	0.6	13.1	5.0			1440	761	47.2	15.9	318	141	40	25	22	$2x10^{11}$			
D	3.0	I_3	875	0.3	12.8	5.0			1490	868	41.7	13.9									
E	1.5	I_2	1100	0.6	12.8	5.0			1462	1143	21.8	14.5									
F	2.0	I_2	1100	0.6	12.8	5.0			1462	1057	27.7	13.9									
G	2.5	I_2	1100	0.6	12.8	5.0			1462	886	39.4	15.8									
H	3.0	I_2	1100	0.6	12.8	5.0			1462	769	47.4	15.8									
4A	3.0	I_2	1100	0.6	15.4	5.0	98		1547	840	45.6	15.0				25		$2.8x10^{11}$	2.9	0.3	89
B	3.5	I_2	1100	0.6	15.2	5.0	97		1490	786	47.2	13.5									
C	4.0	I_2	1100	0.6	15.0	5.0	97		1490	745	50.0	12.5									

* SO_2 normalized to 5% excess oxygen

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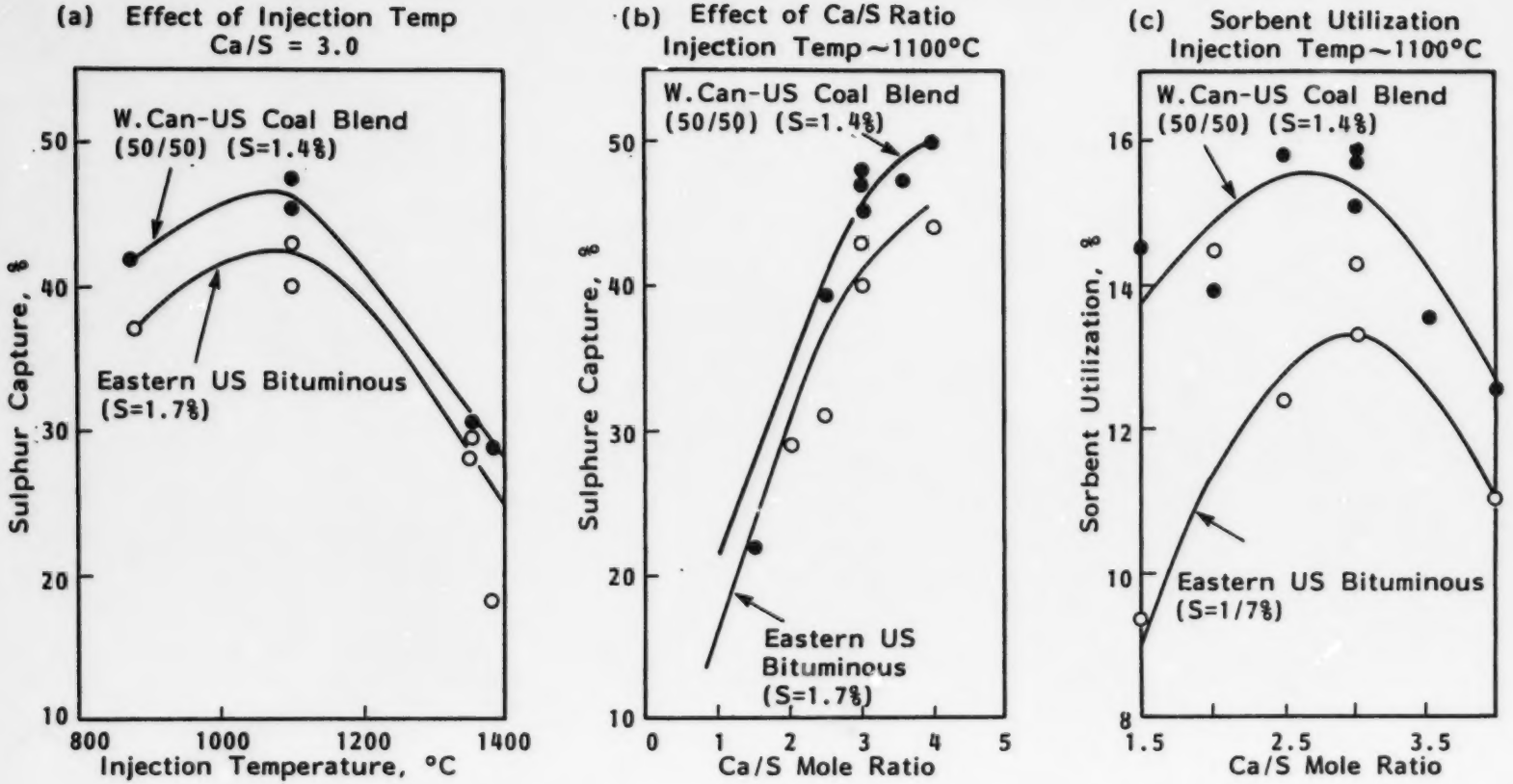

FIGURE 7.

COMPARISON BETWEEN WESTERN CANADIAN-US COAL BLEND
AND EASTERN US BITUMINOUS COAL

Lakeview TGS Quenching Rate, 500° C/s
Beachville Limestone, 8.6 μm MMD

burning the blended coal, as compared to 43% in case of the US coal/5/. Sorbent utilization curves are also similar for the two coals (Figure 7C): 16 and 14% respectively at Ca/S ratio of 3.0. Sulphur dioxide emission was reduced from 1.1 g SO_2/MJ to 0.58 g SO_2/MJ for the US coal and from 0.96 g SO_2/MJ to 0.52 g SO_2/MJ for the blend.

4.2.2 Effect on Waste Characteristics and ESP Performance

Chemical composition and particle size distribution of ashes from a Luscar coal and from the blend, with and without limestone injection produced at the CRF is given in Table 5.

Particle size distribution of the ashes is shown in Figure 8. The data indicate that the baseline ash from the coal blend has a mass median diameter of about 8 μm while that from the limestone injection ash has a mass median diameter of about 4 μm. This suggests that particle size distribution of the limestone injection waste for the coal blend would not significantly affect ESP performance. The Luscar coal ash has a mass median diameter of about 6 μm.

The dust loading to the ESP increased from 1.2 g/m^3 in the case of the baseline coal to 2.9 g/m^3 with limestone injection. Limestone injection waste contains high levels of CaO and $CaSO_4$. CaO content of the waste is 318 g/kg and $CaSO_4$ 141 g/kg. The waste also contains small amounts of $CaCO_3$, which is probably due to the reaction of CaO and CO_2 in the flue gas.

Carbon content of the baseline ash from the blend is 43 g/kg, and that of the limestone injection waste is 25 g/kg. On a sorbent free basis carbon content of the waste amounts to 46 g/kg, similar to that of the baseline.

The resistivity of the limestone injection waste is about 10^{11} ohm.cm. The precipitator with a collection area of 15 $m^2/m^3/s$ and electric field strength of 2.4 kv/cm collected the waste with an efficiency of 89%. This efficiency is lower than the baseline's collection efficiency of 93%. Low collection efficiencies are the result of the combination of high ash resistivity and high dust loading to the ESP.

4.2.3 Slagging and Fouling Propensities of the Waste

Although particulate loading to the ESP increased significantly, no slagging was observed in the furnace. Soft deposits were observed on the furnace walls and heat exchanger surfaces. These deposits could be easily blown away by compressed air, suggesting that conventional soot blowing equipment may suffice for full scale boiler application of limestone injection.

Table 5

Composition of Various Ashes

Chemical Composition g/kg	Luscar Coal	w.Canadian-US Coal Blend (Baseline)	w.Canadian-US Coal Blend with Limestone Injection
Na_2O	14.9	9.8	7.5
K_2O	7.2	10.4	6.5
MgO	16.5	12.0	0.39
CaO	106	64.6	361
Fe_2O_3	48.8	73.0	35.6
Al_2O_3	194	221.0	118
SiO_2	539	438	257
TiO_2	6.80	10.0	6.0
SO_3	11.80	19.0	82.2
LOI	42.3	138	11.9

Ash Particle Size Distribution

Sieve Opening µm	Cumulative % Passing		
	Luscar Coal	w.Canadian-US Coal Blend (Baseline)	w.Canadian- US Coal Blend (Limestone Inj. Ash)
2	9	15	3
4	33	51	12
8	57	90	50
16	94	95	91
32	99	99	98
40	100	100	100
50	100	100	100

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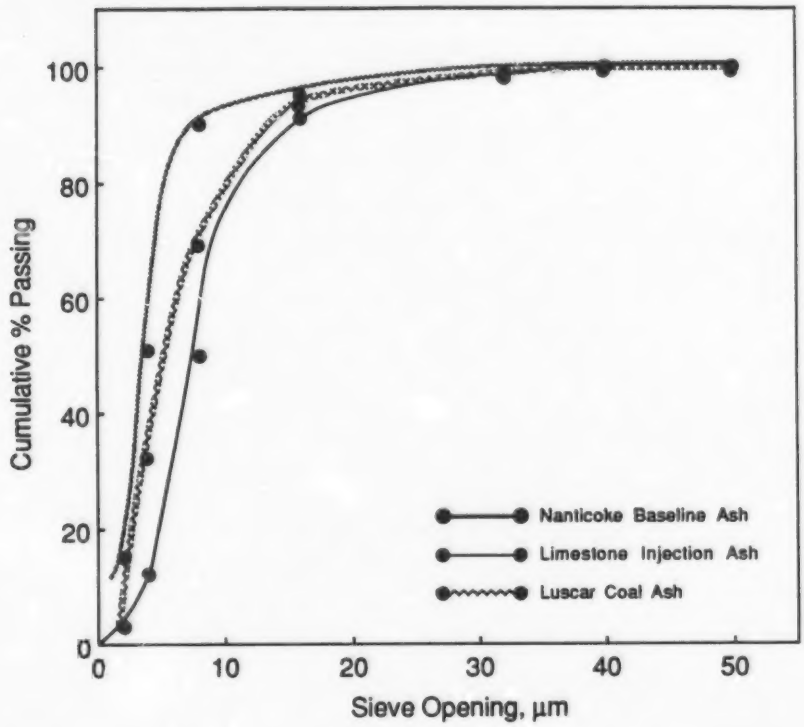

FIGURE 8
PARTICLE SIZE DISTRIBUTION OF ASHES

5.0 CONDITIONING OF LUSCAR COAL ASH AND LIMESTONE INJECTION WASTE

Both the Luscar coal flyash, and the limestone injection waste have high resistivities. High resistivity of the flyash is known to limit the performance of the ESP. Even a thin layer of high resistivity ash, deposited on the collecting plates, reduces the current flow between the discharge electrodes and the collection plates: with reduced current levels, the time required for the charging is lengthened, and consequently the particle migration velocity is decreased resulting in the reduction of the precipitator collection efficiency.

5.1 CONDITIONING OF LUSCAR COAL ASH

Luscar coal produces flue gases with 225 ppm SO_2 content. Ash resistivities are high, ranging between 2.7×10^{10} to 1.4×10^{11} ohm.cm depending on the carbon content of the ash. The pilot precipitator performed only with 79% efficiency. SO_3 conditioning, the injection of SO_3 vapour into the flue gas stream was studied, by injecting various amounts of SO_3, ranging from 30 to 80 ppm into the flue gas at approximately 140°C. The residence time from the injection point to the precipitator was 1.5s. The results are summarized in table 6.

The effect of increasing SO_3 concentration in the flue gas on ash resistivity is plotted in Figure 9. The two curves correspond to a high (3.3%) and a low (0.8-2.8%) ash carbon level in the baseline ash. Ash resistivities decrease with increasing SO_3 concentration in the flue gas, up to about 60 ppm. Further increase in SO_3 level has only very small effect on resistivity. SO_3 conditioning reduces ash resistivity by 0.7 to 1 order of magnitude in the low carbon ash from 1.3×10^{11} to 1.2×10^{10} ohm.cm and in the high carbon ash from 2.7×10^{10} to 4×10^{9} ohm.cm. Lower ash resistivities are reflected in improved ESP performance: outlet dust loading was reduced from 0.16 to 0.12 g/m^3, and collection efficiency increased by about 6%.

5.2 CONDITIONING OF LIMESTONE INJECTION WASTE

In the limestone injection process calcium sulphate and unreacted calcine are carried with the flue gas as entrained particulates and are collected downstream with the flyash in the ESP. The reaction product and unreacted sorbent increase the particulate loading by a factor of two to three, depending on the sulphur content of the coal and the Ca/S stoichiometry used. An increase in inlet loading results in a corresponding increase in outlet emissions if the particle size distribution and ash resistivity remain the same. This problem is further compounded by high resistivity of the calcium compounds in the ash, resulting in further degradation of precipitator efficiency. Since these increased emissions are not acceptable, methods for restoring ESP performance have been evaluated. The upgrade options include: increasing collection area by enlarging the ESP, pulse energization and methods to decrease ash resistivity, such as SO_3 conditioning and water conditioning. Water conditioning also decreases gas volume by lowering gas temperature, thus increases effective specific collection area (SCA).

Table 6

SO_3 Conditioning of Luscar Coal Ash

Furnace Quenching Rate: 500°C/S
Coal Feed Rate: 16.5 kg/h

Run No.	SO_3 Injection ppm	FLUE GAS COMPOSITION				ASH		ESP PERFORMANCE		
		% O_2	% CO_2	ppm CO	ppm SO_2	% LOI	Resistivity ohm.cm	Dust Loading g/m^3 Before	Dust Loading g/m^3 After	% Efficiency
2A	Nil	5.0	14.8	74	225	3.3	2.7×10^{10}			
B	40	5.0	14.8	74	225	3.3	3.7×10^{9}			
C	30	5.0	14.8	74	225	3.3	4.0×10^{9}			
3A	Nil	5.0	15.8	31	225	0.8	1.4×10^{11}	0.78	0.16	79
B	10	5.0	15.8	31	225	0.8	3.7×10^{10}	0.78	0.12	85
4A	Nil	5.0	15.7	44	225	2.8	1.3×10^{11}			
B	40	5.0	15.7	44	225	2.8	4.3×10^{10}			
C	50	5.0	15.7	44	225	2.8	1.2×10^{10}			
D	80	5.0	15.7	44	225	2.8	1.8×10^{10}			

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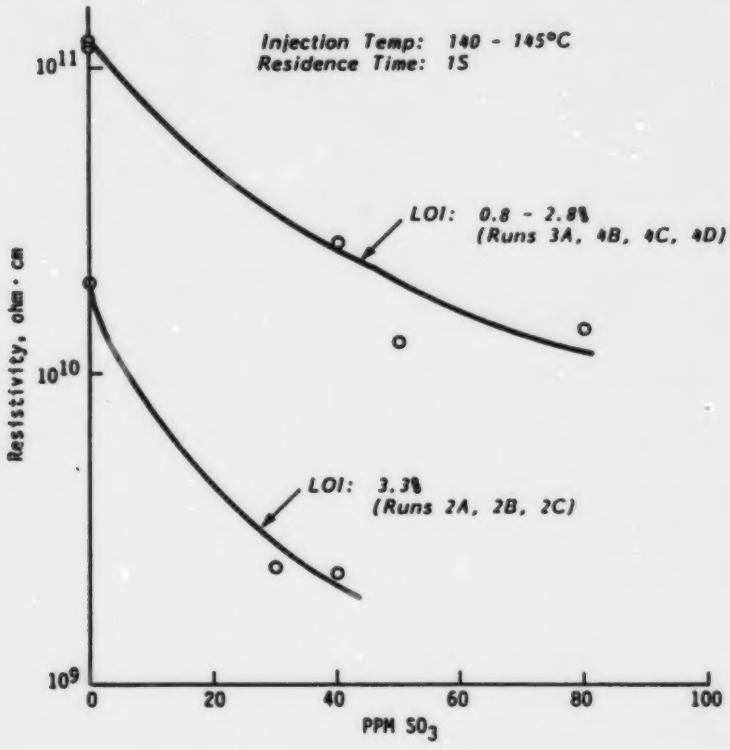

FIGURE 9
SO_3 CONDITIONING OF LUSCAR COAL

Conditioning of the limestone injection waste from the coal blend was carried out using both water and SO_3. The results are summarized in table 7. Injecting 100 to 140 ml/min of water corresponding to a relative humidity of 51 to 58% reduced the waste resistivity from 2.8×10^{11} ohm.cm to 1.8×10^{8} ohm.cm and improved the efficiency of the ESP by 7%. SO_2 capture in the humidifier was up to 13.6% bringing the total SO_2 capture up to 59%.

The effect of 60 ppm SO_3 injection on waste resistivity as a function of residence time between the injection point and the ESP is shown in figure 10 and table 7. The data show that only about 0.5 s residence time is necessary to a drop in resistivity from about 10^{11} to 10^{8} ohm.cm. The corresponding ESP performance improvement was 5-6% and dust emissions were reduced from 0.31 to 0.2-0.26 g/m^3.

SUMMARY

Ash conditioning for improved ESP performance can be a viable option for reducing particulate emissions when firing low sulphur coals or coals with sorbent injection. In this study, SO_3 was used to condition a low sulphur western Canadian coal, SO_3 and water were used to condition waste from limestone injection while burning a coal blend of western Canadian and US coal. The results of the study conducted at Ontario Hydro's 640 MJ/h combustion facility are summarized below:

- A western Canadian 0.3% sulphur coal from the Luscar Mine of Alberta produces ash with resistivities ranging 10^{10} to 10^{11} ohm.cm, which cannot be collected efficiently by existing ESP. Conditioning the ash by injection 50 ppm SO_3 into the gas stream reduced ash resistivities by 0.7 to 1 order of magnitude and increased ESP performance by 6%.

- Limestone injection into the furnace for controlling SO_2 emission produces a high resistivity waste containing ash and high levels of $CaSO_4$ and CaO. Both SO_3 and moisture conditioning were effective in both reducing waste resistivities and improving ESP performance. Water conditioning of the limestone injection waste was found to be slightly more effective than conditioning with SO_3. Humidification of the waste to a 58% relative humidity reduced the resistivity from 10^{11} to 10^{8} ohm.cm and improved the efficiency of the ESP by about 7%. SO_3 conditioning by injecting 60 ppm SO_3 reduced the ash resistivity by up to 3 orders of magnitude and improved the performance of the ESP.

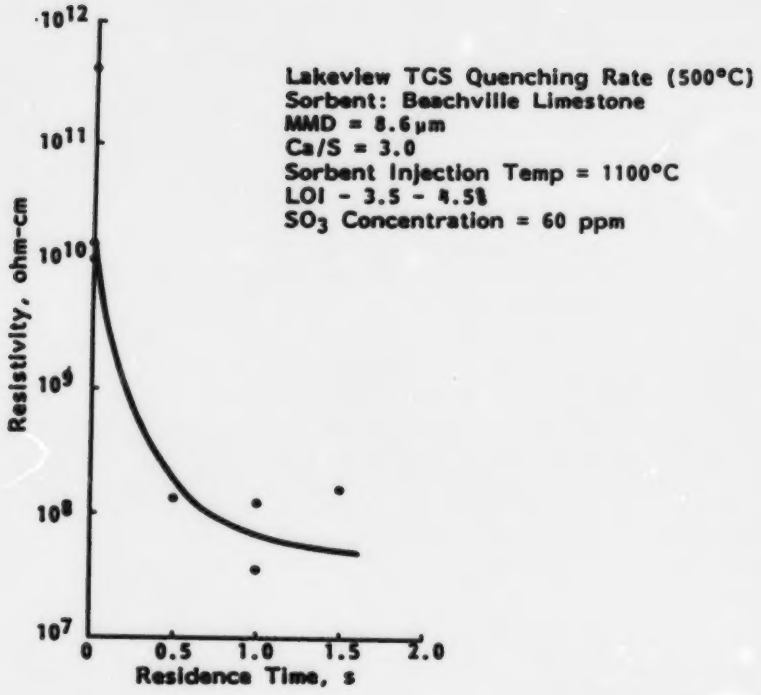

FIGURE 10
SO_3 CONDITIONING
RESISTIVITY VS RESIDENCE TIME

Table 7

Effect of Humidification and SO_3 Conditioning on Particulate Removal - LI Waste

Nanticoke Coal Blend:	S = 1.4%
Furnace Quench Rate:	500°C/S
Ca/S ratio:	3.0
Furnace Injection Temp:	1100°C
Beachville Limestone:	MMD = 8.6 μm
Firing Rate:	420 MJ/h

(a) Humidification

Run No.	HUMIDIFICATION		% SO_2 Capture			ASH		ESP Performance		
	Water Flow cc/min	% Relative Humidity	In-furnace	Humidifier	Total	LOI %	Resis. ohm.cm	Dust Loading g/m^3 Before ESP	Dust Loading g/m^3 After ESP	Eff. %
Baseline 5 Hum A			45.3	-		3.5	2.8×10^{11}	2.8	0.3	89
B	100	51	45.3	5.7	51.0	4.5	1.8×10^{8}			
C	120	54	45.3	11.3	56.6	4.5	1.8×10^{8}	2.4	0.08	96
	140	58	45.3	13.6	58.9	4.5				

(b) SO_3 Conditioning

Run No.	In-furnace SO_2 Removal %	SO_3 Injection ppm	SO_3 Injection Residence Time to ESP, s	ASH LOI, %	ASH Resis. ohm.cm	ESP Performance Dust Loading g/m^3 Before ESP	Dust Loading g/m^3 After ESP	Eff. %
Baseline	43.6	-	-	3.5	1.3×10^{10}	2.5	0.31	87
of	46.1	-	-	4.5	6.2×10^{11}			
6 SO_3 Inj		100	1.0	3.5	3.7×10^{9}	3.1	0.26	92
7 SO_3 Inj	47.3	100	1.0	3.9	3.6×10^{10}			
7 SO_3 Inj	47.2	75	1.0	3.9	3.7×10^{10}			
12 SO_3 Inj	46.2	50	1.0	4.5	3.3×10^{9}			
12 SO_3 Inj	46.2	30	1.0	4.5	1.2×10^{9}	2.9	0.20	93
13 SO_3 Inj	46.2	60	0.5	4.5	2.0×10^{8}			
	46.2	60	1.0	4.5	1.8×10^{8}			
	46.2	60	1.5	4.5	2.9×10^{8}			
	46.2	60	1.0	4.5	5.9×10^{7}			

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RECOMMENDATIONS

A full scale test program is recommended to test the conditioning agents SO_3 and moisture when burning low-S w.Canadian coal or coal blends and when burning coals with limestone injection. Pilot scale testing of more conditioning agents such as ammonia, ammonium sulphate, knwon to affect both ash resistivity and cohesivity is also recommended.

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